NORMAL MODE MODEL DEVELOPMENT AND APPLICATION TO GEOACOUSTIC INVERSION BENCHMARKS

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LONG TERM GOALS

The long term goal of this project is to develop efficient and robust normal-mode modeling tools for research and analysis in underwater acoustics and to apply the tools to the problem of geoacoustic inversion. The modeling tools developed will continue to be distributed to other researchers in the field.

OBJECTIVES

The primary objectives for this fiscal year were to make improvements to the ORCA normal mode model and to apply the model to the geoacoustic inversion benchmark problems. ORCA's capabilities were enhanced to allow the modeling of Gaussian beam sources and to include the effects of the branch line integral(s). In addition, we worked to make ORCA's mode-finding and broadband algorithms more robust and efficient, and we responded to problems that users at other research facilities encountered.

APPROACH

To model Gaussian beam sources using normal mode theory, we used the approach of assigning imaginary components to the point source position, which to our knowledge has not been done before. For a point source in free space, it is easy to show that the field $p=\exp(ikr)/r$, where $r=[(x-x_s)^2+(y-y_s)^2+(z-z_s)^2]^{1/2}$, is a Gaussian beam in real space (x,y,z) when the source components (x_s,y_s,z_s) are given imaginary components. The direction of the beam is determined by the ratios of the imaginary parts of the source coordinates, and the beam becomes sharper as the point source is placed farther in imaginary space. In terms of ORCA's implementation, the $\mathrm{Im}(z_s)$ affects the evaluation of the mode functions at the source point $f_n(z_s)$, and the $\mathrm{Im}(x_s)$ affects the evaluation of the horizontal range R. Since the mode functions in ORCA are computed analytically in each layer using either complex exponential or Airy functions, evaluation at complex values of depth posed little difficulty.

Our approach to including the branch line integral (BLI) in normal-mode calculations was to eliminate it through the use of a gradient halfspace. The BLI is produced by the evaluation of the vertical wavenumber in the homogeneous halfspace below the waveguide. The BLI is usually ignored in normal-mode implementations but can be important when a mode lies near the branch point. In addition, the discontinuity in the complex k plane across the branch line causes numerous difficulties when searching for modes, especially in the broadband problem. Our approach to solving this problem was to replace the homogeneous halfspace with one that has a gradient in sound speed and/or attenuation. The branch point and BLI are eliminated altogether, and the BLI is replaced, in effect, by a series of modes that "stitch together" the former discontinuity. Our objective is to choose a gradient that closely resembles the original homogeneous halfspace problem and that introduces as few additional modes as possible.

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We also used funds from this project to participate in the ONR-sponsored Geoacoustic Inversion Workshop. A nonlinear least-squares (NLLS) optimization algorithm originally developed for nuclear physics applications was used in conjunction with the ORCA normal mode model to solve the various benchmark problems. Since the NLLS approach was found to work well with at most five or so unknown parameters, the set of unknowns for each inversion problem was subdivided into groups, which were then solved for individually. For example, data observations at high frequency and longer ranges were used to invert for the parameters to which those observations were most sensitive: the water depth, source position, and surficial values of sound speed and attenuation. Parameters deep in the sediment were found using low frequency data at short range and fixing the parameters already determined.

WORK COMPLETED

The Gaussian beam source capability has been incorporated into the latest version of the ORCA normal mode model. The method has been applied to a variety of interesting problems and the results reported at the Hawaii ASA meeting. The gradient halfspace approach to eliminating the branch line integral has also been implemented in a developmental version of ORCA. A JASA paper is in the process of being written on the method. The NLLS algorithm and parameter-division approach were developed and refined in the process of applying them to the Geoacoustic Inversion Benchmark problems. The results were presented at the June 1997 Workshop in Vancouver, BC, and have been submitted for publication in a special issue of the Journal of Computational Acoustics.

RESULTS

An example of the new Gaussian beam source capability in ORCA is given in Fig. 1. The Schlieren photograph on the right is for a 1.95 MHz, 2-cm wide Gaussian beam impinging on a water-steel interface [Ngoc and Meyer, J. Acoust. Soc. Am. **67**, 1149 (1980)]. The ORCA-generated image on the left is for a 40-cm thick water layer above a stainless steel bottom. A Gaussian beam at the Rayleigh angle of 58.8° is produced at a depth of 30 cm. The notch in the reflected beam and the beam displacement are produced by the rapid phase change in the reflection coefficient at the Rayleigh angle. A total of 1044 modes were used.

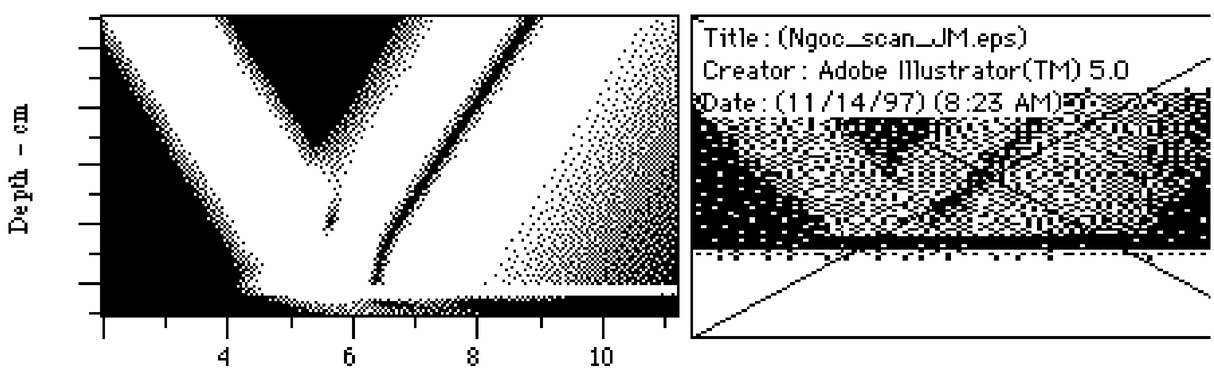

Figure 1. Comparison of modeled (left) and experimental (right) results for a 2-cm wide, 1.95 MHz beam impinging on a water-steel interface at the Rayleigh angle of 58.8°.

The Airy gradient halfspace method is illustrated in Fig. 2. We consider a 40-m thick Pekeris waveguide with sound speeds of 1500 and 1625 m/s in the water and bottom at 100 Hz. ORCA finds modes by computing the downward- and upward-looking reflection coefficients R_1 and R_2 at a reference depth, following the $|R_1\ R_2|=1$ contour in the complex k plane, and identifying modes at points where $\arg(R_1\ R_2)=0$ as well (see dots). In Fig. 2(a) the bottom is a homogeneous halfspace, which gives rise to the Pekeris branch cut across which $R_1\ R_2$ is discontinuous. Two trapped modes to the right of the cut and one leaky mode to the left are found. In Fig. 2(b) the bottom has been given an attenuation gradient, which causes the cut to be replaced by a set of modes representing the BLI of the former problem. The vertically oriented $|R_1\ R_2|=1$ contour in Fig. 2(b) is obtained by placing the reference depth in the top of the halfspace instead of in the water. Use of this reference depth makes the "branch cut modes" easy to find.

IMPACT/APPLICATIONS

The ORCA normal mode model is used extensively at ARL:UT and at a number of other research facilities. Examples of our applications include: (1) simulation of broadband data on horizontal planar arrays in the study of array design and localization algorithms for ADS and ASTO applications, (2) modeling of broadband shot time series measured in the ACT II and other experiments, and (3) generation of broadband replica vectors for MFP. The fluid-only broadband option in ORCA has been used by Peter Nielsen at SACLANT as the basis for a broadband adiabatic normal mode model. The leaky mode features of ORCA are currently being incorporated into an ARL:UT model that is being reviewed as a Navy standard model. ORCA was also chosen as the propagation engine by many of the participants in the Geoacoustic Inversion Workshop, an application that tests the accuracy, speed, and robustness of any model. The code and documentation for ORCA are available via FTP.

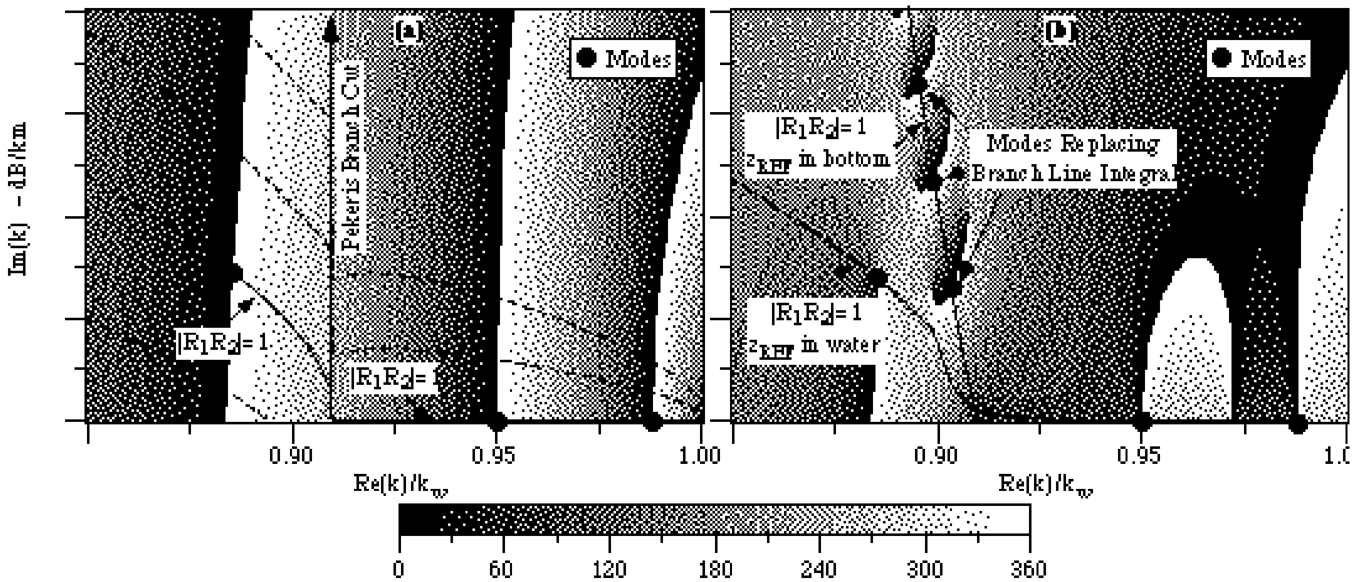

Figure 2. Mode structure in complex k *plane for (a) Pekeris waveguide with a homogeneous halfspace and (b) an Airy gradient halfspace. The phase of R_1R_2 is imaged, and contours of $|R_1R_2|$ are overlaid. Modes correspond to points where R_1R_2=1. The Pekeris branch cut evident in (a) is replaced by a set of modes in (b). The other modes are not affected significantly.*

TRANSITIONS

Information related to transitions is given in the previous section.

RELATED PROJECTS

The ORCA model and the NLLS work are related to the ONR-sponsored Geoacoustic Inversion Benchmark Workshop.

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